Assessing Seismic Hazard in Puerto Rico and the Virgin Islands Using the Historical Earthquake Record and Mixed-Mode GPS Geodesy: Collaborative Research Between the University of Puerto Rico-Mayaguez and the University of Texas at El Paso

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Element I
Seismology, source characteristics

Investigations undertaken:

Our research involved the collection and modeling of seismograms for historic (M>6.0) earthquakes occurring in the Puerto Rico/Virgin Islands (PR/VI) region between 1915 and 1963 (Figure 1, Table 1) as well as study of recent (post-1963) earthquakes within the region. The earthquake source parameters, including slip vectors and seismic slip rates, will be compared to rates and directions of regional deformation determined from a mixed-mode GPS Geodesy study conducted by colleagues at the University of Puerto Rico-Mayaguez (now at the University of Arkansas). The GPS studies will be completed by the summer of 2002.

A graduate student, Ms. Christina Rodriguez, is using joint hypocenter relocation techniques (e.g. Pujol, 1992) to analyze onshore seismicity of southwestern Puerto Rico, the most seismically active onshore region, and invert first motion data (Robinson and McGinty, 2000) to obtain an estimate of the orientation of the regional stress field. The stress field information will aid in determining which faults in the region are optimally oriented for failure in the present stress regime. The research forms part of her MS thesis, which she is expecting to complete no later than December 2001.

Results of the waveform modeling studies for events near Puerto Rico were presented at the Fall 2000 meeting of the American Geophysical Union by Ms. Rodriguez and Ms. Flores (Rodriguez et al., 2000, invited paper). Ms. Rodriguez received an outstanding student presentation award for her meeting poster. Dr. Doser presented further results of the Puerto Rico and Virgin Islands studies at the April 2001 meeting of the Seismological Society of America (Rodriguez et al., 2001). We have completed a manuscript (Doser et al., 2001) on our results for a special volume of Tectonophysics devoted to the seismotectonics of the Puerto Rico-Virgin Islands region.

Results:

The PR/VI region is located within a zone of complex, oblique subduction. East of the region, trench normal subduction of North America beneath the Caribbean plate occurs along the Lesser Antilles arc. West of the region, the buoyant Bahamas Bank sits upon the North American plate, resisting subduction and causing a transition from subduction to transform motion along the northern boundary of the Caribbean plate. South of Puerto Rico subduction also occurs along the Los Muertos Trough, with the Caribbean plate thrust beneath the Greater Antilles crust. The trough appears to die out within the western Virgin Islands (~65.5°W).

Thus the PR/VI region behaves as a rigid microplate (Byrne et al., 1987) sandwiched between four seismogenic zones: the Puerto Rico trench to the north, the Muertos trough to the south, the Mona Canyon to the west, and the Anegada Passage to the southeast. This complex tectonic setting has produced numerous large to great earthquakes, although most have occurred prior to 1960, and little is known about the relationship between these events and the regional tectonics.

In order to study the earthquakes of the PR/VI region we divided the region into two areas, based on the clustering of historic and recent events. The first region, located west and northwest of Puerto Rico, is dominated by seismicity associated with the Puerto Rico Trench and strike-slip faults within the Greater Antilles crust (Septentrional fault, North Puerto Rico Slope fault). The region is located at the eastern edge of rupture in the 1946 great (M_w=8.0) Hispaniola earthquake and includes the 1943 (M_w=7.8) North Mona Passage earthquake. The Virgin Islands form the second study area.

The waveform modeling technique of Baker and Doser (1988) was used in the body waveform inversion process. We used the crustal velocity model of Huerfano (1995) combined with the structural cross sections of Dolan et al. (1998) to construct near-source velocity models for the waveform modeling process.

Northwestern Offshore Puerto Rico

Waveform analysis was conducted for 7 events (Figure 1) within the northwestern offshore region. Our analysis included the 1943 North Mona Passage mainshock. Dolan and Wald (1998) had previously studied this earthquake (Table 1), but have not published a complete, detailed account of their waveform modeling analysis procedures and results.

The earliest event of our study occurred in 1915 west of the 1943 mainshock. The sparse waveform data are most consistent with rupture on a reverse/thrust fault at a depth of ~ 15 km. This places the earthquake above the plate interface in a region where two recent reverse/thrust events have occurred.

Waveform modeling of the 1916 southeastern Hispaniola earthquake (Figure 1) suggests it occurred on a reverse fault within the Greater Antilles crust. Its mechanism is similar to some of the aftershocks of the 1946 great Hispaniola earthquake (Dolan and Wald, 1998).

The 1917 North Mona Passage earthquake appears to have occurred at the western edge of the 1943 aftershock zone (Figure 1). Waveform modeling results suggest it represents strike-slip faulting within the North American plate.

Of special interest to this study was analysis of the 1918 Mona Canyon earthquake (Figure 1). This earthquake generated a tsunami that struck the western coast of Puerto Rico with the loss of over 100 lives, making it one of the most devastating earthquakes in the history of Puerto Rico. Mercado and McCann (1998) modeled tsunami runup heights for the earthquake, suggesting the earthquake occurred along a series of four normal faults striking 185°-235° with lengths of 4 to 31 km and displacements of 4 m. Our results are consistent with their multiple fault rupture models. The complexity of the source-time function we obtain indicates slip along at least two faults striking ~210°, each ~18 km long with ~ 3 m average slip. Time differences between the two greatest pulses of moment release suggest the event ruptured toward the south.

Mechanisms and focal depths for the 1920, 1943 mainshock and 1943 aftershock all suggest rupture along the plate interface (Table 1). Our results for the 1943 mainshock are consistent with those of Dolan and Wald (1998) (Table 1). Dolan and Wald suggest that rupture

in the 1943 mainshock propagated in the down dip direction and that the lateral extent of the rupture zone was related to the collisional underthrusting of a portion of the Bahamas Bank (Mona Bank). This is consistent with the aftershock pattern and the hypocentral location of the 1943 aftershock we studied. Note that rupture in 1920 was also updip and at the western edge of the 1943 mainshock rupture (as defined by Dolan and Wald, 1998). Thus in the ~30 years prior to the 1943 mainshock, seismic events were concentrated at the edges of the 1943 rupture zone.

Virgin Islands Region

Historic and recent seismicity of the Virgin Islands is considerably less than that of northwestern offshore Puerto Rico, although the southwestern Virgin Islands experienced an M~7.75 earthquake (McCann, 1985) in 1867. We studied three events in this region (Figure 1), as well as an event in 1939 located well to the north of the Puerto Rico trench.

Sufficient data were not available for waveform inversion studies of the 1927 earthquake. For this event we generated synthetic seismograms using focal mechanisms of recent earthquakes and compared these results to the observed waveforms. The waveforms of the event suggest reverse/thrust faulting above the plate interface (Table 1).

Waveform inversion suggests reverse faulting at the plate interface in 1919 and a strike-slip mechanism for the 1930 earthquake (Table 1). Projecting the focal depth of the 1930 event on to the plate interface model of Dolan et al. (1998) suggests the earthquake occurred on the plate interface. We feel it is more likely the 1930 event occurred within the subducted North American plate, involving only a slight change in the plate interface model of Dolan et al. (1998) that would also make it more consistent with the positions of recent earthquakes.

Limited data for the 1939 earthquake, located well north of the Puerto Rico trench, are consistent with normal faulting within the North American plate at a depth of ~10 km. The earthquake thus appears to be an outer rise event.

Seismic Moment Rates

Jansma et al. (2000) suggest that about 85% of North American/Caribbean plate motion takes place upon the faults located north and northwest of Puerto Rico, with the remainder to the south. This is in good agreement with moment release over the past ~75 years, with 87% of moment release occurring along structures located north and northwest of Puerto Rico. Another 13% of the moment release took place within the Mona Passage region, where extension rates are estimated to be 2 to 5 mm/yr (Jansma et al., 2000). Note that only 1% of the total moment release has occurred within the Virgin Islands region. Thus, the seismic results are in good agreement with GPS studies.

<u>Non-technical Summary:</u>

All magnitude >6.0 earthquakes in the Puerto Rico-Virgin Islands region occurred prior to 1945; thus little is known about the structures that caused these earthquakes. Our study addressed this lack of knowledge by collecting and modeling seismograms of these earthquakes to determine their depths and causative faults. The results will be integrated with global positioning satellite (GPS) measurements of crustal motion to determine the rate and style of seismic versus non-seismic regional deformation. This information will provide important new constraints for regional seismic hazard maps and building/infrastructure design.

Reports Published:

Doser, D.I, C. M. Rodriguez and C. Flores, Historical earthquakes of the Puerto Rico-Virgin Island region (1915-1943, submitted to special volume Tectonophysics, October, 2001.

Rodriguez, C.M., D.I. Doser and C. Flores, Historical seismicity of offshore Puerto Rico and the Virgin Islands (1915-1943), Seismol. Res. Lett. 72, 276, 2001

Rodriguez, C.M., D.I. Doser and C. Flores, Historic and recent seismicity of offshore western Puerto Rico, invited abstract, Eos 81, 1182, 2000.

Availability of Data Sets:

Copies of historical seismograms (in paper or digital form), seismic catalog information and phase/waveform data for selected high quality events in southwestern Puerto Rico are available upon request from the principal investigator, Dr. Diane Doser, (915)-747-5851, doser@geo.utep.edu

Table 1 – Source Parameters of Historic Earthquakes

Date	Time	Location* (lat,long)	Focal Mechanism (strike,dip,rake)	Depth (km)	Mo+	Mw
101115	1933	19.04 –67.28	286,12,68**	20	4.5	6.4
042416	0426	18.26 –68.53	281±38,50±10,105±20	16±7	19±3	6.8
072717	0101	19.16 –67.66	65±28,80±17,-170±13	36±7	22±4	6.9
101118	1414	18.28 –67.62	207±22,54±8,-127±28	20±7	64±7	7.2
060919	0604	19.36 –64.77	153±30,40±10,80±20	30±6	2.4±1.2	6.2
021020	2207	19.07 –67.28	70±40,30±21,70±30	27±7	5.7±2	6.5
080227	0051	19.10 –64.43	317,84,122**	20±8	0.5	5.6
062530	1206	18.72 –64.78	167±25,87±18,168±25	50±5	1±0.4	6.0
120639	0405	20.41 –65.90	310,65,-120**	10±5	1.5	6.4
072943	0302	18.99 –66.97	50±21,30±16,30±24	29±3	529±30	7.8
			60,20,60	>25	---	7.9 (Dolan and Wald, 1998)
073043	0102	19.17 –66.86	60±40,30±17,45±30	24±3	1.1±0.2	6.0

*Locations from Russo and Bareford (1993) and Russo (pers. comm., 1995).

+in N-m x 10^{18}

**results from forward modeling

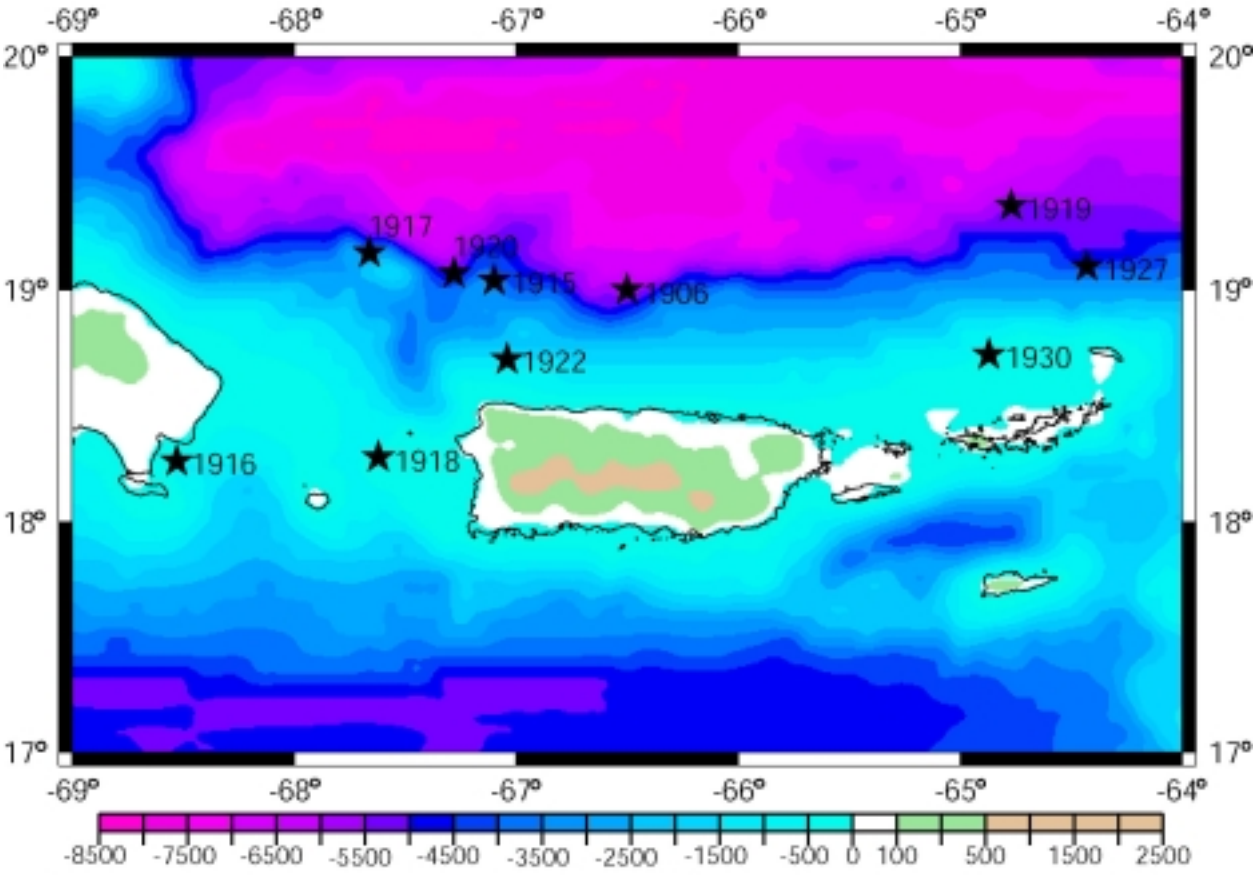

Figure 1 – Historic earthquakes (M>6.0) of the Puerto Rico region (stars).